AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 104:513–528 (1997)

Bone Mineral Density and Survival of Elements and Element Portions in the Bones of the Crow Creek Massacre Victims

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KEY WORDS bone mineral density; taphonomy; Crow Creek site

ABSTRACT The interpretation of archaeologically-derived skeletal series is dependent on the elements and portions of elements preserved for examination. Bone and bone portion survival is affected by factors, both intrinsic and extrinsic to the elements themselves, that influence deterioration and preservation. Among the intrinsic variables, the density of the element and element portion are particularly important with respect to the degree of preservation. Recently reported bone mineral density values from a contemporary human sample are compared to the survival of prehistoric limb bones of the Crow Creek specimens, a fourteenth-century massacre skeletal series. The contemporary density values are positively correlated with Crow Creek element and element portion survival. Two calculations of bone mineral density, however, are more closely related to preservation than a third. Such density information has implications for assessing minimum number of elements and individuals and documenting taphonomic processes. Am J Phys Anthropol 104:513–528, 1997.

Although bone density values have long been used in archaeological interpretations, the introduction of technology specifically designed to nondestructively determine bone density has permitted its use in more widespread applications. These methodologies allow for direct assessment of bone elements and element portions and enable us to address the taphonomic implications of variation in bone mineral density.

The primary focus of previous work is on archaeological faunal analysis. The single photon absorptiometer was used by Lyman (1982) to calculate the densities of bone tissue in deer elements and correlate these with survival of element portions. Lyman and others have continued to expand the number of species for which density measures are available. Data are published for pronghorn antelope and domestic sheep (Lyman, 1984), bison (Kreutzer, 1992), camelids (Elkin, 1995) and salmon (Butler and Chatters, 1994). This work focused attention on the intrinsic properties of bones as determinants of their survival. In addition to density, other authors have discussed the influence of bone shape, size and mass. Before the role of human selectivity as a force in causing patterns of element frequencies could be addressed, a better understanding of alternative, equally valid, processes of structuring assemblages is required (Lyman, 1991; 1992).

Theoretical discussions have developed over the interpretation of body segments, butchery units and utility indices (Gifford-

Contract grant sponsor: Werner-Gren Foundation for Anthropological Research; Contract grant number 5251; Contract grant sponsor: U.S. Corps of Engineers, Omaha District; contract grant number DACW45-78-C-0018; Contract grant sponsor: Summer Scholars, CSUC University Foundation.

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Received 12 June 1995; accepted 3 August 1997.

Gonzalez, 1989; Lyman, 1992). These discussions have not included human skeletal remains because it has been assumed that human skeletons usually do not enter, as most nonhuman remains, the archaeological record as a by-product of food consumption. Despite the probability that most human burials result from the careful and deliberate inhumation of entire, or almost entire, individuals, relative bone density is important for predicting which elements should survive, understanding the absence of specific elements, and interpreting the events which may have affected preservation between the time of death and the eventual recovery and analysis by the archaeologist and the skeletal biologist.

The present study provides an archaeological case study to explore the relationship between bone density and preservation. Density values derived from a contemporary sample (Galloway et al., 1997) are compared with rates of element survival among the Crow Creek massacre victims. The results show a high positive correlation between density and survival and provide a different perspective on events at Crow Creek and upon the process of density-mediated survival of bone.

CROW CREEK MASSACRE SITE

The Crow Creek skeletal material, consisting of nearly 500 individuals killed ca. 1350 AD, is well suited for analyzing survival of human bone elements and element portions because these remains were subjected to a variety of pre- and post-burial taphonomic processes. The Crow Creek Site is a large, well-fortified prehistoric village (Fig. 1) located in south-central South Dakota (Kivett and Jensen, 1976; Zimmerman et al., 1981). Situated on a high terrace, the site is immediately north of the confluence of the Missouri River and Crow Creek; the Missouri River flood plain forms the west side of the site and the Crow Creek flood plain forms the south side of the site. The third side of the site is formed by a 1,250 foot-long fortification ditch including 10 bastions. There were, at one time, at least 50 lodges at the site, now indicated by shallow basin-shaped depressions.

Earlier archaeological investigations identified two major prehistoric components. The younger of the two, the Wolf Creek component of the Initial Coalescent Variant, is of importance here (Kivett and Jensen, 1976; Lehmer, 1971).

In the spring of 1978, skeletal remains were found eroding from the northwest end of the fortification ditch. Before arrangements could be completed between the Crow Creek Sioux Tribe, the U.S. Army Corps of Engineers, Omaha District, and the Archaeology Laboratory at the University of South Dakota (USD), a looter dug into the *in situ* bone bed, leaving a large hole and scattering bones down the talus slope. A preliminary analysis of the looted remains indicated that approximately 45 individuals were represented, including men, women and children (Willey, 1978). Full-scale excavations took place between August and December 1978 to recover the additional human bones visible in the back of the looter's hole. A bone bed 2.5 m wide, 6 m long, and 1.5 m deep was uncovered (Fig. 2). The recovery is more fully discussed in Zimmerman et al. (1981) and Willey and Emerson (1993).

MATERIALS AND METHODS

The Crow Creek massacre skeletons

The skeletons were studied at USD. The osteological analyses included age and sex estimations, cranial and limb bone measurements, cranial and dental nonmetric observations, paleopathology, and element and mutilation inventories. The minimum number of individuals recovered was 486 based on the number of right temporals present (Willey, 1990). At the end of May 1979, the bones were returned to the Crow Creek Sioux Reservation for reburial, which occurred in August 1981.

The osteological analysis, combined with the archaeological context of the material, indicated that the Crow Creek skeletons represented villagers murdered during a single event. Over 40% of the most complete crania displayed unhealed depressed fractures, primarily on the front and sides of the cranial vaults (Willey, 1990). This figure is likely a conservative estimation of potentially lethal blows to the head, since fragmen-

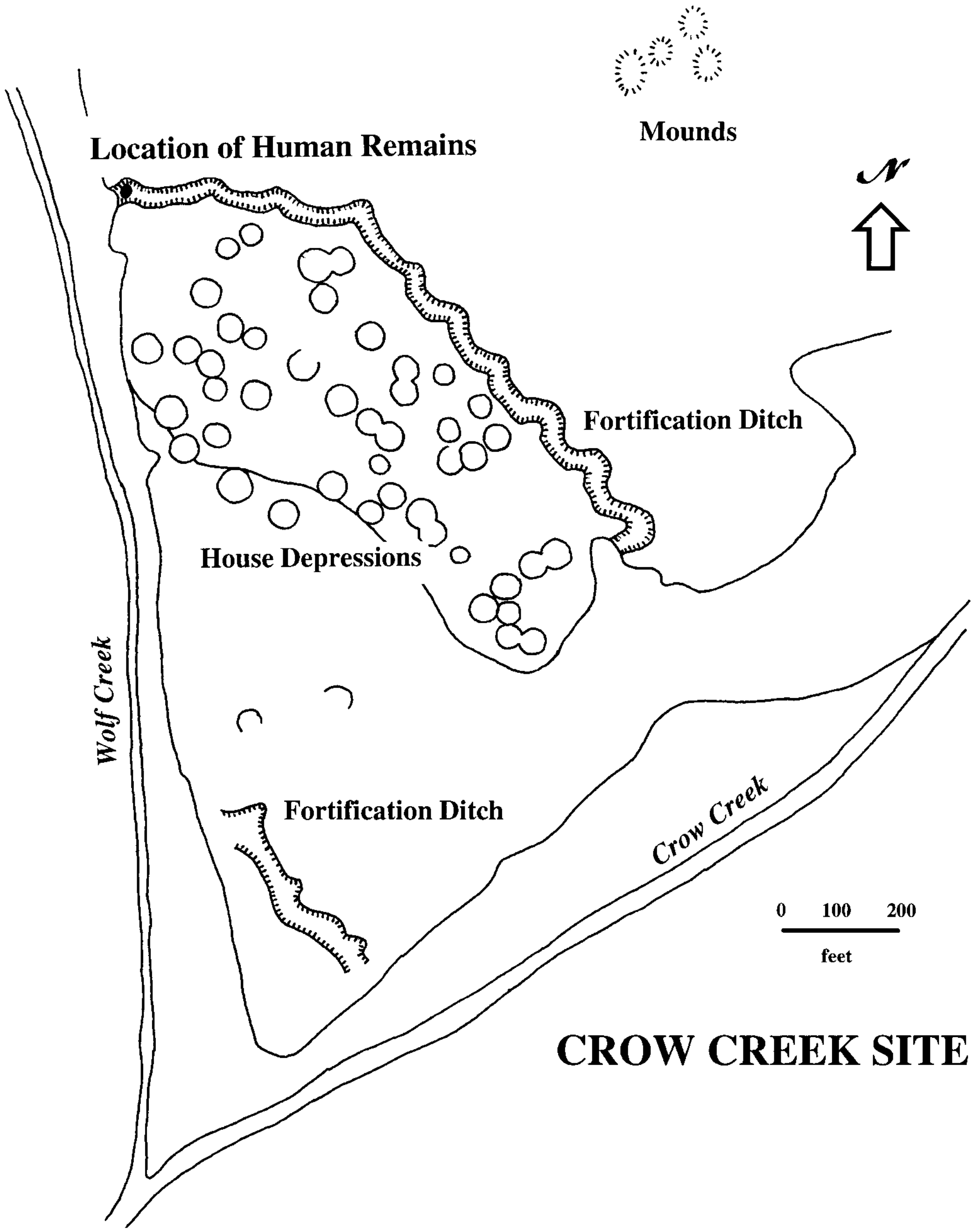

Fig. 1. Map of the Crow Creek Site showing location where massacre victims were excavated. (Modified from Kivett and Jensen, 1976; Fig. 1.)

tary cranial material, omitted from this tally, would likely increase the percentage. Bodies also showed evidence of mutilation. Cuts suggesting scalping or scalping attempts occurred on approximately 90% of the more complete frontals (Willey, 1990). Decapitations, as interpreted from cuts on the first cervical vertebrae, occurred in nearly 25% of the individuals (Willey, 1990). Nasal areas were occasionally cut, teeth were evulsed, and a few postcranial elements were cut, suggesting dismemberment

Fig. 2. The western portion of the main Crow Creek bone bed. View is toward the north. (From Willey, 1990; Fig. 2.)

(Willey, 1990). A few of the elements displayed light burning or smoking.

Following the raid, it appears that the bodies lay exposed on the ground surface, during which time they were scavenged, most likely by the village dogs and perhaps by coyotes and wolves. The Crow Creek elements displayed many chewing marks, characterized by crushed edges and puncture marks on the bone. Approximately 22% of the femora, for example, were chewed (Fig. 3; Willey, 1990). If the raid occurred in cold weather, as has been suggested (Willey, 1990) based on the absence of insect pupal cases in the assemblage, then the remains were frozen and perhaps thawed. The bodies, including those that had become disarticulated, were later gathered, perhaps by Crow Creek villagers who had escaped the raid or perhaps by members of an affiliated village. The remains were placed in the end of the fortification ditch and covered with a thin layer of clay. A thin scattering of bones above the main bone bed may represent a secondary gathering of bones or where scavengers dug into the main bone bed. While in the ground, the body parts continued to decompose and the bone layer became compacted. Further disturbance was caused by rodents tunneling into the bone bed.

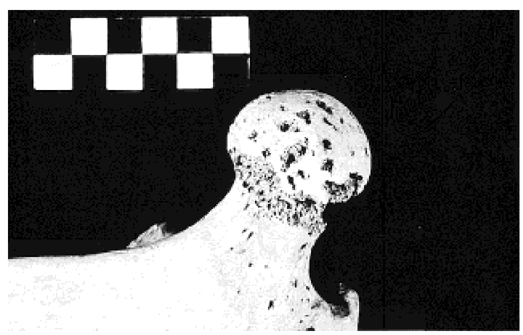

Fig. 3. Chewed femur head from Crow Creek Site. Scale is in centimeters. (From Zimmerman et al., 1980; plate 5.)

Besides the pre-discovery taphonomic processes, a number of modifications to the assemblage took place following discovery. The west end of the bone bed was exposed by

erosion at least by May 1978 and those bones were subsequently looted. The USD excavators exposed, removed, bagged, and transported the bones to the university. There, the materials were cleaned with water and brushes before storage in sacks and boxes. Elements were inspected by researchers on at least six different occasions, each time involving removal, examination and replacement in the bags and boxes. Despite these potentially damaging activities, the skeletal material was generally well preserved, although sometimes fragmentary and incomplete.

Identification of the specific consequences of these taphonomic processes is impossible in most instances. However, given the variety of taphonomic processes, from perimortem, post-depositional through post-excavational, the Crow Creek materials provide an appropriate sample to test the relationship between bone density and element survivability.

The limb bone sides and portions present were observed in 1979. The portion of the element still present was estimated without recourse to measurement or direct comparison with complete elements. The element portions were recorded in fractions (eighths, sixths, fourths, thirds, and halves; Fig. 4), by portion (proximal, distal, shaft), and by side (left, right). The most incomplete specimens were omitted from the inventory.

The Crow Creek bone segments were counted and summed. Survival of the bone element segments was converted to a survival percentage by dividing the number of element segments recovered by the maximum segment count for that element.

Sex and age assessments of adult remains for paleodemographic purposes were determined from the innominates in the sample. Those results indicate a sex ratio that was not statistically different from equality, at least when all adult ages are combined (Willey, 1990). When the adult sex ratios are examined by age, however, there are statistically significant differences between the sexes (Willey, 1990). Generally, young males outnumber young females, and old females outnumber old males.

Age determination from the long bones was estimated in a separate assessment based on the degree of attachment of epiphyses and/or size of the element. Only adult Crow Creek specimens and those elements identified as "adult or adolescent" were included in the present study. The sex and more exact adult age of the individual limb elements were not determined, so for this analysis, all adult elements, regardless of sex and age, were combined.

The contemporary sample

The contemporary sample was drawn from skeletal remains at the Anthropology Department, University of Tennessee-Knoxville. The present series consists of 10 female and 22 male adults (age $>$ 15 years) of known age and primarily of European ancestry. Skeletonization was accomplished through long-term exposure above ground, with persistently adhering tissues being removed through boiling. Information on the handedness of the individuals in the study series was unavailable.

The number of individuals scanned at each bone location varied depending on the element and side. Bones were not scanned at specific sites if these locations were damaged. Materials with gross pathological conditions were also excluded, however, histological changes which may have affected bone mineral content could not be excluded. The maximum number of females measured at each scan location was nine (minimum 6) and the maximum number of males was 22 (minimum 15).

Two major concerns in the choice of comparison samples are 1) differences in ancestry between the modern and archaeological samples and 2) diagenetic changes which may occur during the extended period of burial for the archaeological sample contrasted with the exposure and cleaning methods used on the modern sample. Direct comparisons of reference and Native American bone densities are limited to one study which used dual photon x-ray absorption (McHugh et al., 1993). That study found significantly greater lumbar bone density and total body bone density (2.1 to 8.1%) in the age-matched adult Native American women compared to reference standards derived from "white" women. Individuals of African ancestry are known to have as much

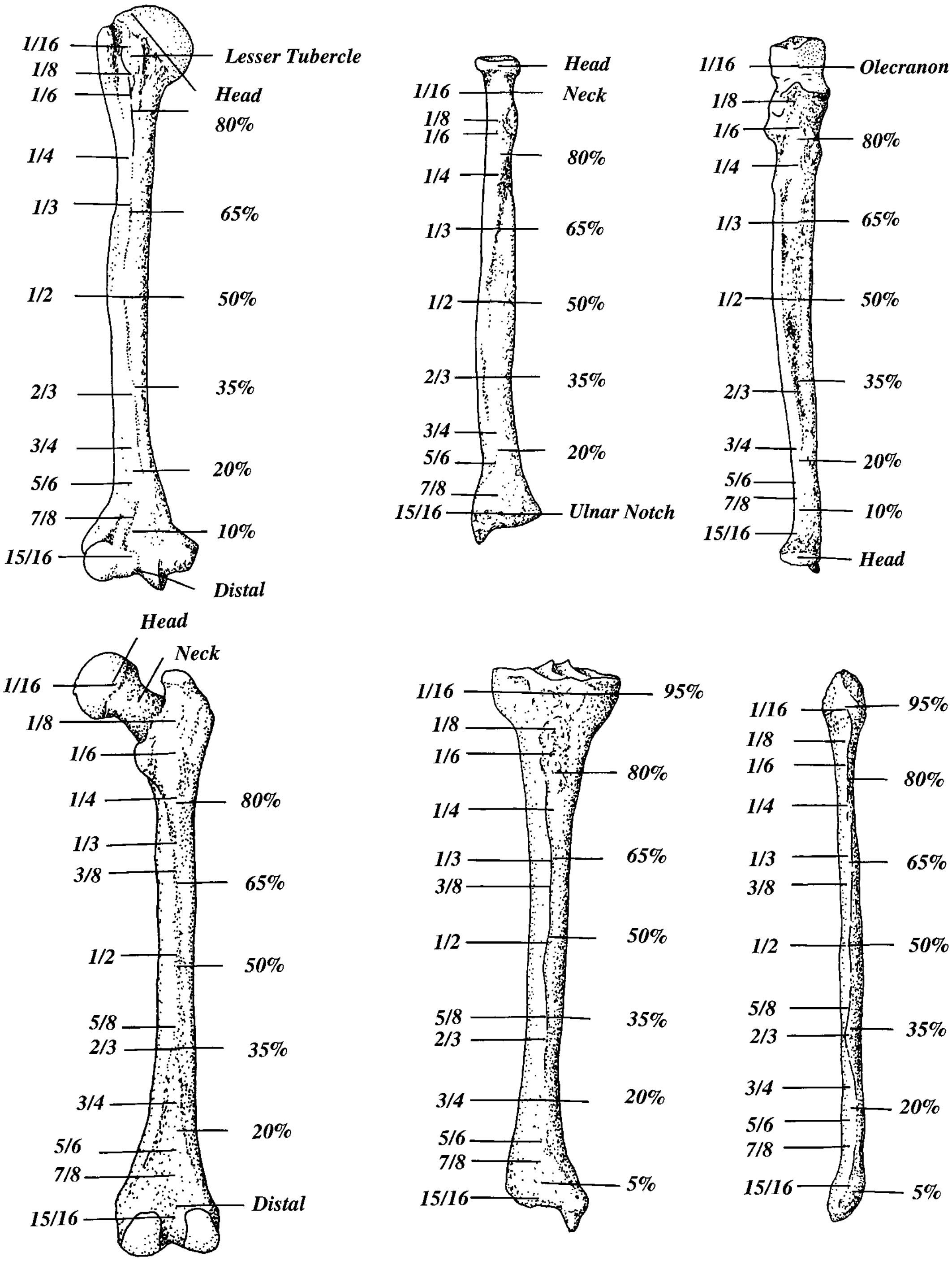

Fig. 4. Comparison of Crow Creek segments (presented in fractions to left of each bone) and contemporary scan locations (in percentages to right).

as 12% greater bone mineral density than the reference standards (Cohn et al., 1977; Nelson et al., 1991).

Diagenetic changes in stable isotopes show that the exchange of minerals with the surrounding soils varies considerably by the type of hard tissue, the extent of the surface exposure, the integrity of the collagen structure, and the actual element (reviewed in Price et al., 1985; and Schoeninger, 1995). Calcium, the primary component of the inorganic phase of bone tissue, has been shown to leach into soils surrounding burials (Lambert et al., 1983). In contrast, other studies find that calcium can be deposited into bone from the surrounding matrix (Klepinger et al., 1986). Prediction of actual loss over time, therefore, is difficult given the inability to determine accurately the pre-death status of the bone mineral from archaeological samples.

The processing of contemporary material may have had an affect on bone mineral density although no preservatives or consolidants were used. Some elements or individuals may have sustained more exposure or processing than others. Maceration and prolonged boiling techniques may cause as much as 10% loss of bone mineral density and may have had an influence in this study (MacDonald, 1991).

Single photon absorptiometry

A Norland Cameron Single Photon Absorptiometer (SPA), using a monochromatic radionuclide source, Iodine-125, was employed to determine the density of bones placed in the path of the highly collimated photon beam (Cameron and Sorenson, 1963). A scintillation detector counted and converted the transmission of photons into an estimation of bone mineral content and density based on comparisons with ashed samples. The equipment was chosen to meet the requirements of replicability and to be comparable to that used in other studies of bone mineral density.

The equipment uses an algorithm to convert the scan result ($T_b = [\log_e (I_o^*/I)]/[m_b r_b - m_m r_m]$) into a measure of density (Cameron and Sorensen, 1963). In essence, the machine measures the difference between the photon beam as it passes through a baseline material (I_o^*) and the intensity of the beam as it passes through the bone and baseline (I). The amount of mineral present in the bone (T_b) is calculated from the differences in the photon streams and mass absorption coefficients of bone mineral (m_b) and of tissue (m_m). The measure I is taken at closely spaced intervals across the bone allowing reconstruction of a cross-section density profile. The technique is highly accurate and precise when these ideal conditions are met.

For irregularly shaped bones, however, the results are less accurate. Single photon absorptiometry assumes the density is evenly distributed throughout the scanned cross section. Because long bones have medullary cavities, bone is concentrated into the denser cortical bone than predicted by the scan results. The algorithm also assumes a circular bone cross section to calculate the thickness of the bone and distributes the amount of mineral measured over the assumed area. This process ignores differences in long bone cross-sectional morphology. Other causes of technical errors include beam hardening, photon beam size, and scattered radiation. Despite these problems, accuracy has been reported at 1–4% and precision at 2–4% (U.S. D.H.H.S., 1986).

In this study, four scans were taken at each site and the results were averaged. Sheets of ¼″ plexiglass, substituting for the "soft tissue" baseline, were placed beneath the bone to maintain a baseline adequate for accurate measurement of density. Sheets were adjusted at each scan site to minimize the number of zero counts which occur when the bone density eliminates passage of photons. The actual number of sheets reflected a compromise between these opposing requirements. Repeat scans of the same bone were made during the course of the study to check replicability of the methodology.

Total diaphyseal lengths were used to determine the scan sites on the six major limb bones: humerus, radius, ulna, femur, tibia and fibula (see Fig. 4). On each bone, sites at 20%, 35%, 50%, 65%, and 80% of the length measuring from the distal end were included. In addition, sites at the distal and proximal ends which conformed to major morphological landmarks were also measured.

At each scan site, the thickness of the bone was measured with sliding calipers. Thickness is defined here as the distance between the top and bottom of the bone in scan orientation. Width of the bone was machine measured by the bone scanner. Circumference was taken with a linen tape at each scan site. The tape was oriented to take minimum circumference and did not adhere to the concave contours of the bone. The scan locations and positioning in the bone scanner differed depending on the element. The humerus, radius and ulna were scanned with the anterior surface uppermost. The femur was scanned with the posterior surface up, except for the distal location which was scanned with the lateral surface up to meet the maximum width capabilities of the equipment. The tibia, except the proximal end, was scanned with the posterior surface up; the proximal end was scanned with the lateral surface up. The fibula was scanned perpendicular to the long axis with the lateral surface up.

Bone density measurements

The SPA provides 1) bone mineral content (BMC) in gm/cm, 2) bone width (BW) in cm and 3) bone mineral density in gm/cm^2. BMC is calculated assuming a cylindrical bone which is then size corrected by dividing with the machine-measured width. This calculation provides an areal density—bone mineral density (BMD) in gm/cm^2. Basic descriptive statistics were produced for the modern female and male samples as well as the overall modern sample.

The bone scan sites used in this study were often of irregular cross-sectional shape: some were high and narrow, while others were low and wide. Because irregular bone shape may distort the calculated BMD, two additional measurements have been used.

Volume density (VD) was obtained by dividing the bone mineral density by the thickness of the bone at the scan site and provides values in gm/cm^3. VD is a measure commonly used in zooarchaeological taphonomic studies (viz. Lyman, 1982).

Bone density by circumference (BMDc) was calculated by dividing the BMC by the average bone diameter at the scan location. Average bone diameter was estimated by measuring the circumference at the scan site and dividing that figure by pi (3.14), yielding a figure in gm/cm^2. None of these measures, however, accurately reflect the actual distribution of mineral in the bone because they all presume a solid rather than a hollow cylinder.

These bone density values (BMD, VD, and BMDc) have been published in a previous paper (Galloway et al., 1997, Tables 1–3). There the densities are presented by element side, sex and ancestry.

Comparing Crow Creek segments and contemporary bone densities

The relationship between scan locations of the contemporary sample and the Crow Creek element segments were sometimes imprecise. If a scan location was "bracketed" by two segments, then the counts from both adjacent segments were averaged to estimate the number present. For example, the humerus 50% scan location fell exactly on the point common to the Crow Creek humerus segments ⅓–½ and ½–⅔ (Fig. 4). So the number in the ⅓–½ segment and in the ½–⅔ segment were added together and divided by one-half. That average was used to compare the Crow Creek segments with the contemporary bone densities. Similar adjustments were made for the other scan locations and element segments and are presented in Table 1. The averaged number of segments at locations comparable to the scan locations are presented in Table 2.

The density values for both sexes in the contemporary sample (Galloway et al., 1997) were averaged to facilitate comparison with the unsexed Crow Creek archaeological material. The mean density values for the contemporary sexes were "averaged" without weighting for the different sample sizes by sex. Comparisons were first made separately using the right and the left sex-averaged values. Then these contemporary values for the upper and lower limbs were analyzed. Finally the relationship between the contemporary bone density values (BMD, BMDc, and VD) and bone segment survival was tested by Spearman Rank-Order Correlation (Thomas, 1986). This association was calculated for the six limb bones by side (using averaged male and female mean val-

TABLE 1. Comparable bone density scan locations and Crow Creek element segments. Scan location percentages are proportions from the distal toward the proximal end; segment fractions are from the proximal toward the distal end

Scan locations	Segments	Scan locations	Segments
Humerus		Radius	
Head & lesser tuberosity[1]	0–1/16 & 1/16–1/8	Head	0–1/16
80%	1/8–1/6 & 1/6–1/4	Neck	0–1/16 & 1/16–1/8
65%	1/4–1/3 & 1/3–1/2	80%	1/8–1/6 & 1/6–1/4
50%	1/3–1/2 & 1/2–2/3	65%	1/4–1/3 & 1/3–1/2
35%	1/2–2/3 & 2/3–3/4	50%	1/3–1/2 & 1/2–2/3
20%	3/4–5/6 & 5/6–7/8	35%	1/2–2/3 & 2/3–3/4
10%	7/8–15/16	20%	3/4–5/6 & 5/6–7/8
Distal	15/16–1	Ulnar notch	7/8–15/16 & 15/16–1
Ulna		Femur	
Olecranon	0–1/16 & 1/16–1/8	Head & neck[2]	0–1/16 & 1/16–1/8
80%	1/8–1/6 & 1/6–1/4	80%	1/8–1/6 & 1/6–1/4
65%	1/4–1/3 & 1/3–1/2	65%	1/4–1/3 & 1/3–3/8
50%	1/3–1/2 & 1/2–2/3	50%	3/8–1/2 & 1/2–5/8
35%	1/2–2/3 & 2/3–3/4	35%	5/8–2/3 & 2/3–3/4
20%	3/4–5/6 & 5/6–7/8	20%	3/4–5/6 & 5/6–7/8
5%	7/8–15/16 & 15/16–1	Distal	7/8–15/16 & 15/16–1
Head	15/16–1		
Tibia		Fibula	
95%	0–1/16 & 1/16–1/8	95%	0–1/16 & 1/16–1/8
80%	1/8–1/6 & 1/6–1/4	80%	1/8–1/6 & 1/6–1/4
65%	1/4–1/3 & 1/3–3/8	65%	1/4–1/3 & 1/3–3/8
50%	3/8–1/2 & 1/2–5/8	50%	3/8–1/2 & 1/2–5/8
35%	5/8–2/3 & 2/3–3/4	35%	5/8–2/3 & 2/3–3/4
20%	2/3–3/4 & 3/4–5/6	20%	3/4–5/6 & 5/6–7/8
5%	5/6–7/8 & 7/8–15/16	5%	7/8–15/16 & 15/16–1

[1] Humerus head and lesser tubercle density values averaged for comparison with Crow Creek element portions.
[2] Femur head and neck density values are averaged for comparison with the Crow Creek elements.

TABLE 2. Number of Crow Creek segments present at scan locations. Numbers at some scan locations are estimated by averaging adjacent segment numbers as described in the methods

	Humerus			Radius			Ulna		
	Left	Right	Total	Left	Right	Total	Left	Right	Total
Proximal[1]	86.5	83.5	170	65	80	145	77	83.5	160.5
Neck				68.5	82	150.5			
80%	145	143.5	288.5	81	94.5	175.5	95.5	105.5	201
65%	154.5	156	310.5	82.5	93.5	176	97.5	108.5	206
50%	160.5	161.5	322	73.5	89.5	163	88	95	183
35%	164	165.5	329.5	73.5	89.5	163	88	95	183
20%	172	168.5	340.5	59	76	135	64.5	73.5	138
10%	151	82	150.5						
5%							27	30.5	57.5
Distal[2]	132	118	250	22.5	31	53.5	18	20	38
	Femur			**Tibia**			**Fibula**		
	Left	Right	Total	Left	Right	Total	Left	Right	Total
Proximal[1]	242.5	253.5	496	142.5	146.0	288.5	78.5	86.5	165
80%	278.5	291.0	569.5	204.5	200.5	405	106	108.5	214.5
65%	269	286	555	217	210.5	427.5	112	112.5	224.5
50%	269	285.5	554.5	221	211.5	432	118.5	117.5	236
35%	266.5	279	545.5	214	211	425	115	114	229
20%	256	266	522	205	204.5	409.5	106	104.5	210.5
Distal[2]	160.5	150.5	311	171.5	171	342.5	77.5	77.5	155

[1] Proximal includes humerus head and lesser tuberosity, radius head, ulna olecranon, femur head and neck, and fibula 95% location.
[2] Distal includes radius notch, ulna head, and tibia and fibula 5% locations.

TABLE 3. Crow Creek segment counts by element and side. All fractions are from the proximal end toward the distal. Percentages (in parentheses) are segment survival by the maximum segment count for that element

	Humerus			Radius			Ulna		
Segment	Left	Right	Total	Left	Right	Total	Left	Right	Total
0–1/16	77	70	147 (42.6)	65	80	145 (81.9)	68	73	141 (67.5)
1/16–1/8	96	97	193 (55.9)	72	84	156 (88.1)	86	94	180 (86.1)
1/8–1/6	143	141	284 (82.3)	75	93	168 (94.9)	93	103	196 (93.8)
1/6–1/4	147	146	293 (84.9)	79	95	174 (98.3)	98	108	206 (98.6)
1/4–1/3	148	152	300 (86.9)	83	94	177 (100.0)	99	110	209 (100.0)
1/3–1/2	161	160	321 (93.0)	82	93	175 (98.9)	96	107	203 (97.1)
1/2–2/3	160	163	323 (93.6)	76	91	167 (94.4)	93	103	196 (93.8)
2/3–3/4	168	168	336 (97.4)	71	88	159 (89.8)	83	87	170 (81.3)
3/4–5/6	174	171	345 (100.0)	61	77	138 (78.0)	67	76	143 (68.4)
5/6–7/8	170	166	336 (97.4)	57	75	132 (74.6)	62	71	133 (63.6)
7/8–15/16	151	145	296 (85.8)	26	33	59 (33.3)	36	41	77 (36.8)
15/16–1	132	118	250 (72.5)	19	29	48 (27.1)	18	20	38 (18.2)
Total	1727	1697	3424	766	932	1698	899	993	1892

	Femur			Tibia			Fibula		
	Left	Right	Total	Left	Right	Total	Left	Right	Total
0–1/16	223	228	451 (78.8)	121	124	245 (56.6)	71	75	146 (61.3)
1/16–1/8	262	279	541 (94.5)	164	168	332 (76.7)	86	98	184 (77.3)
1/8–1/6	277	287	564 (98.6)	200	196	396 (91.5)	105	106	211 (88.7)
1/6–1/4	281	291	572 (100.0)	209	205	414 (95.6)	107	111	218 (91.6)
1/4–1/3	276	291	567 (99.1)	215	210	425 (98.2)	109	112	221 (92.9)
1/3–3/8	269	285	554 (96.9)	219	211	430 (99.3)	115	113	228 (95.8)
3/8–1/2	269	287	556 (97.2)	222	211	433 (100.0)	117	117	234 (98.3)
1/2–5/8	269	284	553 (96.7)	220	212	432 (99.8)	120	118	238 (100.0)
5/8–2/3	269	282	551 (96.3)	217	212	429 (99.1)	118	114	232 (97.5)
2/3–3/4	264	276	540 (94.4)	211	210	421 (97.3)	112	114	226 (94.9)
3/4–5/6	258	268	526 (92.0)	199	199	398 (91.9)	107	109	216 (90.8)
5/6–7/8	254	264	518 (90.6)	190	190	380 (87.8)	105	100	205 (86.1)
7/8–15/16	180	176	356 (62.2)	153	152	305 (70.4)	85	89	174 (73.1)
15/16–1	141	125	266 (46.5)	110	108	218 (50.3)	70	66	136 (57.1)
Total	3492	3623	7115	2650	2608	5258	1427	1442	2869

ues) and total (averaged means for both sides and sexes). In addition to the separate elements, correlations were calculated among upper limb bones (humerus, radius and ulna), lower limb bones (femur, tibia and fibula), and for all elements together.

RESULTS

Crow Creek specimens

Totals of Crow Creek limb bone segments by side and element are presented in Table 3. For all of the elements, the midshaft segments are more frequently represented than the epiphyseal and metaphyseal segments. By element, the femur segments are generally more frequently represented than the segments of the other elements, with distal portions of the radius and ulna being least frequently present. These results are depicted in Figure 5, where the percentages present are based on the maximum count for each element.

More right side segments than left segments are present in the Crow Creek sample (Table 3). The greater number of right segments is statistically significant for the overall distribution ($P < 0.02$). This is largely caused by the influence of side differences in the radius ($P < 0.01$) and ulna ($P < 0.02$), both with more right segments than left. None of the other element side differences are significantly different by themselves.

Comparison of Crow Creek segments and contemporary bone densities

Crow Creek element segment survival and the various contemporary bone mineral density values are highly correlated (Table 4, Figs. 6–7). Spearman Rank-Order Correlation coefficients are significant for the combined sides of each element, each side of each element, all upper limb elements together, all lower limb elements together, and all upper and lower elements together. The correlations are consistent for all bones of the lower limb. For the upper limb, correlations are slightly lower for the radius and exceptionally high for the humerus.

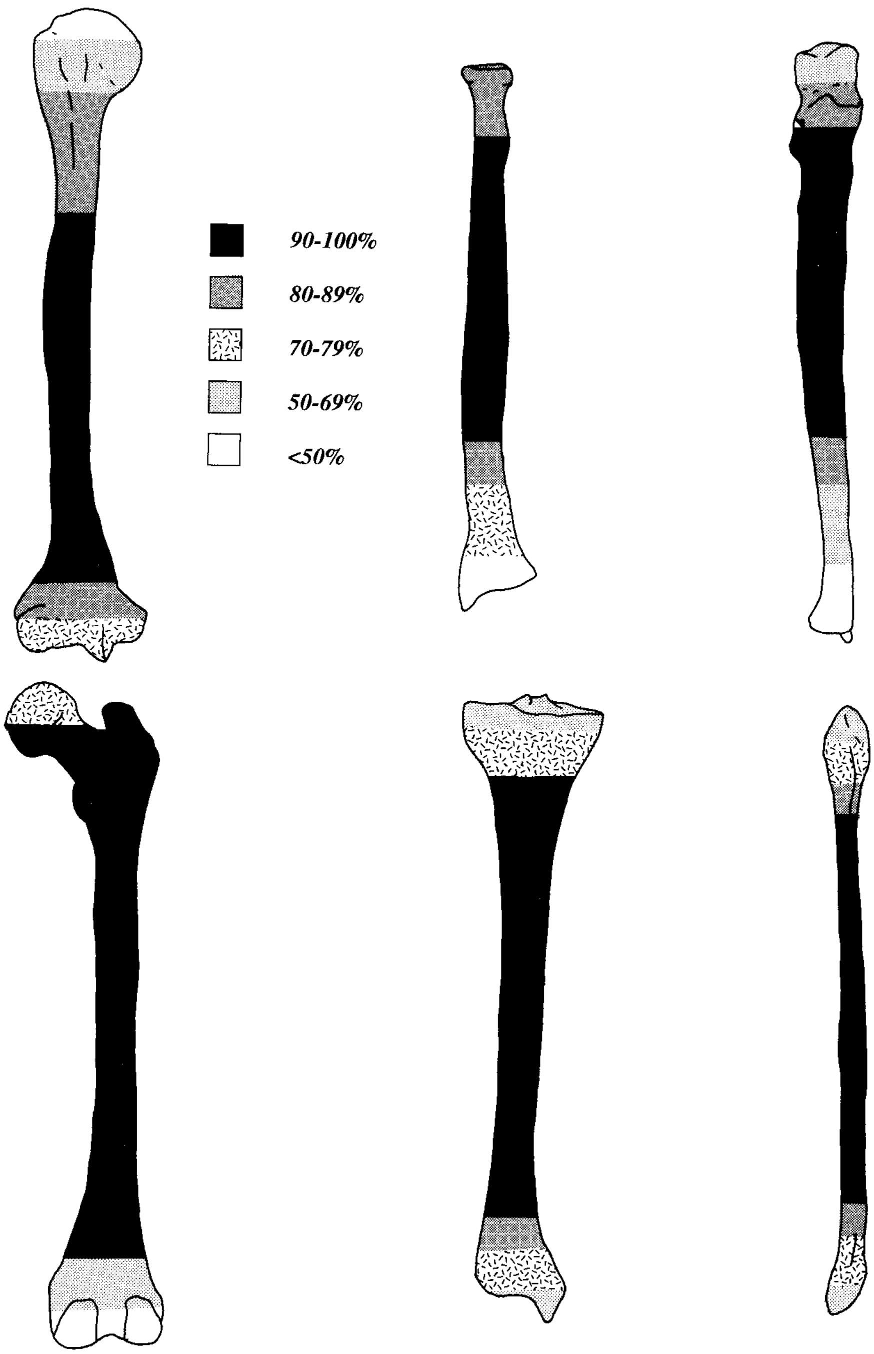

Fig. 5. Survival of Crow Creek limb element segments. Percentages are based on the maximum segment count for each element; left and right sides are combined.

The correlations are strongest between survival and the BMDc, followed by BMD and finally by VD when examined by bone. When multiple bones of a body portion are considered together, the efficiency of the VD decreases. It barely reaches a significant correlation in the upper limb and is not significant in the lower limb. In contrast,

TABLE 4. Spearman Rank-Order Correlation coefficients for mean contemporary sample density values and Crow Creek element survival

	Humerus[1] (8)	Radius (8)	Ulna (8)
Right			
BMD[2]	0.786*	0.714*	0.905**
BMDc[3]	1.000**	0.714*	1.000**
VD[4]	0.952**	0.595	0.786*
Left			
BMD	0.707*	0.731*	0.916**
BMDc	0.994**	0.690*	0.994**
VD	0.881**	0.623	0.743*
Total			
BMD	0.762*	0.707*	0.916**
BMDc	0.976**	0.714*	1.000**
VD	0.833**	0.659*	0.743*
	Femur (7)	**Tibia (7)**	**Fibula (7)**
Right			
BMD	0.775*	0.821*	0.919**
BMDc	0.847*	0.893**	0.919**
VD	0.883*	0.893**	0.642
Left			
BMD	0.786*	0.786*	0.946**
BMDc	0.893**	0.929**	0.919**
VD	0.893**	0.964**	0.556
Total			
BMD	0.786*	0.821*	0.893**
BMDc	0.883*	0.893*	0.893**
VD	0.893*	0.893*	0.600
	Upper limb (24)	**Lower limb (21)**	**Total (45)**
BMD	0.851**	0.874**	0.827**
BMDc	0.903**	0.950**	0.853**
VD	0.370*	0.083	0.096

* $P < 0.05$.
** $P < 0.01$.
[1] Number of pairings by bone and body segment are in parens.
[2] BMD = bone mineral density.
[3] BMDc = bone density by circumference.
[4] VD = volume density.

both BMD and BMDc are both highly correlated, again with BMDc being slightly higher. When the combined long bone scan locations are used, VD does not show an association between density and survival while the other measures show highly significant correlations (Fig. 7).

DISCUSSION

The results of this analysis are relevant to 1) the interpretations of the Crow Creek skeletal material and 2) the use of density measures in analyzing the effects of taphonomic processes in other archaeological contexts.

The case of The Crow Creek massacre victims

For the purposes of this study, we assume that the bone mineral density of the Crow Creek archaeological material is comparable with the contemporary sample's bone mineral density distribution, at least in a relative sense. Although the Crow Creek material is no longer available for analysis, this assumption could be tested using materials from comparable archaeological series.

One of the goals of the original Crow Creek osteological analysis was to determine the minimum number of individuals (MNI) represented in the sample. The MNI was determined by selecting points on the limb and temporal bones that were readily identifiable to element and by side (Zimmerman et al., 1981; Willey, 1990). Points on the limb bones included the mid-deltoid tuberosity for the humerus, the base of the radial tuberosity for the radius, the base of the coronoid process for the ulna, the lesser trochanter for the femur, the anterior crest at the nutrient foramen for the tibia and the distal portion of the fibula. These identification points were selected intuitively; the points were believed to be preserved more frequently than or at least as frequently as any other point for that element.

The present study shows that for certain limb bones there are segments of higher density which may show greater representation than those selected for the MNI counts. While segment counts confirm that some of the intuitively selected points were among or close to the most frequently preserved portions (including the radius, ulna, femur, and tibia), there are exceptions (Fig. 5). The points selected for the humerus and fibula are not the most frequently represented segments for those elements; this discrepancy is especially apparent for the fibula. The minimum counts for these elements may have increased by counting other points nearer their midshafts, although determining the side of those shaft fragments may have been more difficult. Using other, more frequently represented segments would have altered the relative proportions of elements present. It is unlikely, however, that the counts for those under-represented elements would have altered the overall MNI, which was based on the right temporal bone count of 486.

Another earlier conclusion concerning the Crow Creek material also requires re-evaluation in light of the present study. It was

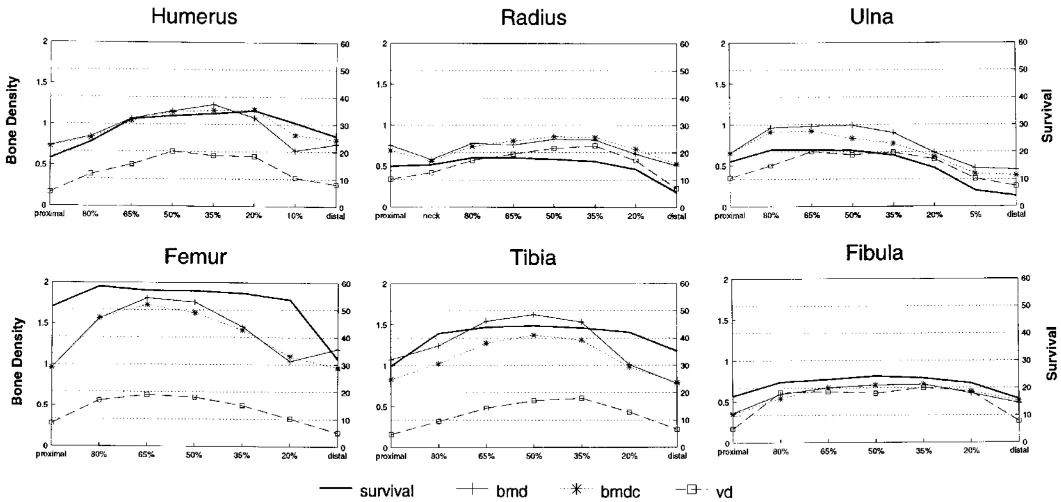

Fig. 6. Comparison of bone mineral density and survival of Crow Creek element segments. Key: **bmd**—bone mineral density, **bmdc**—bone mineral density by circumference, **vd**—volume density.

suggested, based on the MNI count by side, that right elements were more frequently preserved than lefts (Zimmerman et al., 1981), although this difference was not statistically significant (Willey, 1990). These results, based on the MNI element counts, are echoed in the segment counts presented in Table 2. This side preference is also displayed in some of the Crow Creek mutilations. Cuts suggesting the direction of decapitation (occipital near foramen magnum, cervical 1 and cervical 2, Willey, 1990) and cuts on limb bones suggesting dismemberment (Willey, 1990) are more frequent on the right side than the left. It should be noted, however, that cuts on the cranial vault suggesting scalping are randomly distributed by side (Willey, 1990). It seems unlikely, considering the bone mineral densities of the contemporary sample, that bone mineral density alone produces the observed right-left distribution. In the modern sample, ulnar bone mineral densities display some significant side differences, but the radial bone mineral density differences do not (Galloway et al., 1997). One possible explanation is that bone mineral density has only a general effect on survival although the results of this study suggest otherwise. Alternatively, left forearms may have been removed more frequently than right forearms as a part of the Crow Creek mutilations. Based on this study, the side discrepancies appear to result from some such form of human modification rather than other taphonomic processes.

Survival of skeletal elements has also been investigated in cases of suspected cannibalism. Recently, White (1992) and Turner (1993) have identified characteristics which can be used to identify instances where cannibalism occurred. These include differential representation of elements along with such markers as intentional bone breakage, cut marks, burning, anvil abrasions, and "pot polishing." While particular emphasis is placed on the relative lack of vertebrae with such remains, these researchers suggest that the presence of the less dense portions of the limb bones and the fragmentation of more dense diaphyseal regions are also relevant to the question of differential, density-dependent, survival. The cases examined thus far tend to be well-preserved so that extensive taphonomic destruction of skeletal material is of less concern. However, in situations where preservation is less complete, knowledge of relative density within the bones becomes critical.

The possibility of cannibalism must be considered with the Crow Creek material. Many of the classic indicators of such activity are missing in this collection. There is high recovery of vertebral elements and relatively few indications of burning. There is, however, extensive evidence of dismem-

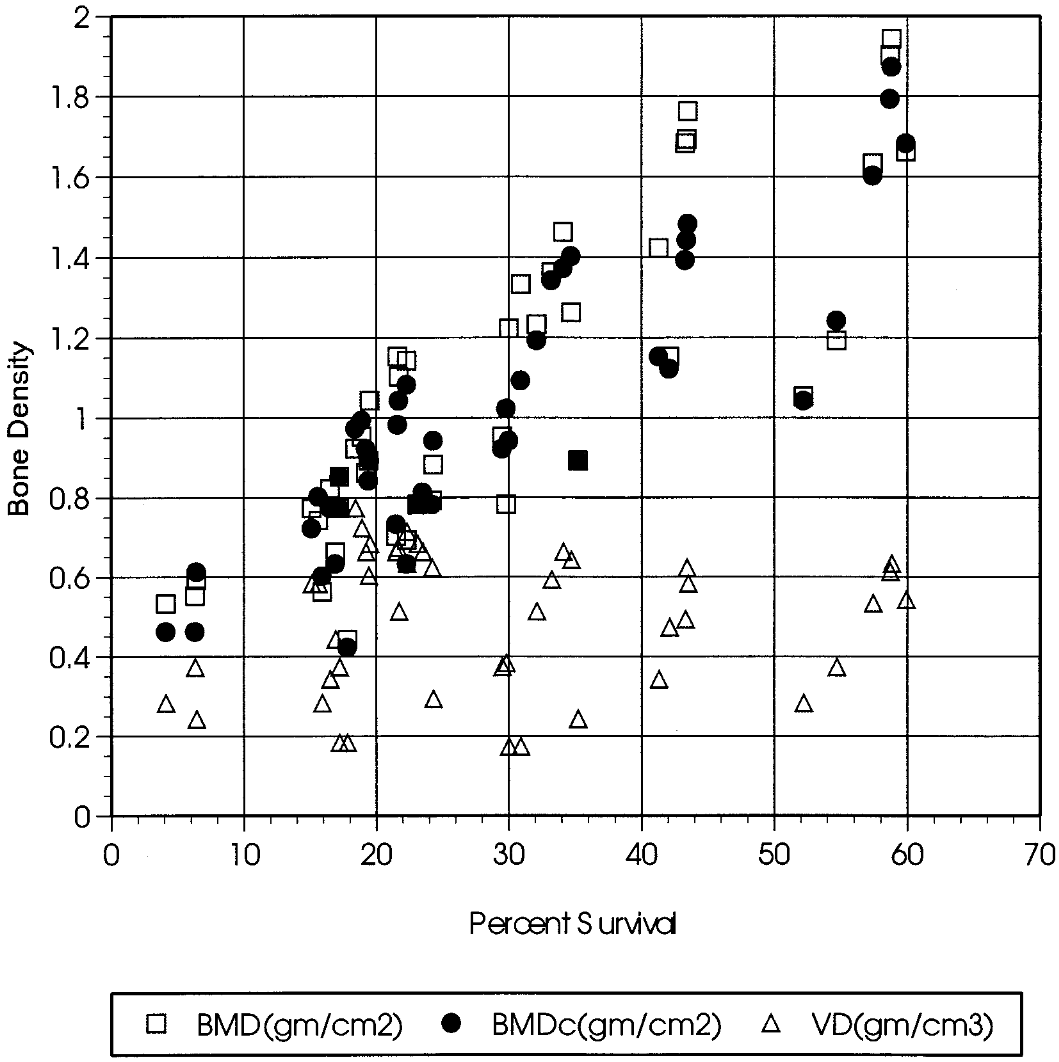

Fig. 7. Comparison of bone mineral density and percent survival for all bones from the Crow Creek site by the measurement technique. Key: **BMD**—bone mineral density, **BMDc**—bone mineral density by circumference, **VD**—volume density.

berment, particularly decapitation by severing the top of the neck. In addition, some long bones show cut marks and others were smashed. It is possible that the smashing occurred in order to avoid cutting through the joints. Splintering of long bones occurs most frequently at the proximal and distal ends suggesting that marrow extraction was not the primary goal. Since there is also carnivore activity recorded in these remains, much splintering may be due to these non-human causes. There is little support for cannibalism occurring at Crow Creek, or at least that it had a major effect on the bone assemblage.

Implications for other archaeological skeletal series

Aside from its immediate applications to the interpretation of the Crow Creek site, this study has implications for the use of bone density measures in taphonomic reconstruction of humans and non-human animals. The presence of selected faunal ele-

ments in archaeological assemblages has long been recognized as resulting in part from human activities, including the kill, butchery, and transport of meat and hides as well as food processing and waste disposal. Similarly, in humans, the mode of death, funerary customs, cemetery reuse or other human disturbance of graves occur hand-in-hand with other taphonomic changes. An understanding of the strength of bone density in filtering this information is crucial before interpretations about other variables can be made.

The present study suggests that although within-element comparisons can be made using any of the three measures employed here, BMDc and BMD are more consistently correlated with survival than is VD. When comparisons across bones are made, BMDc and BMD appear far superior to VD, at least with respect to density predictability in humans.

If this is also the case with nonhuman material, then new measures of density will be needed when looking at survival patterns of "butchery units" or by individual animal rather than by element or element segment. This observation may explain the lack of correlation between density and percent survival reported from other sites (Gifford-Gonzalez, 1989).

The present study indicates that density is an extremely important variable in determining survival of bone in archaeological and forensic contexts. Even with the multiplicity of factors involved in forming the Crow Creek skeletal series, high correlations between density and survival are found. It is evident from this study that bone density is important for predicting which elements will survive. Absence of certain segments, where bone mineral density is low, should be expected as the postmortem interval increases or where environmental conditions are particularly destructive. The absence of bone that is more densely constructed, however, suggests that some form of selection, perhaps by opportunistic scavenging or deliberate human modification of the remains, has occurred.

In the case of the single individual, density along with size and soft tissue factors may explain the presence or absence of elements and element portions. This study provides some foundation for assertions concerning the survivability of specific bones or bone element portions. When mass graves such as the Crow Creek massacre site are encountered, understanding the role of mineral density in element distribution and preservation may be particularly important in refining our interpretations of past events.

SUMMARY AND CONCLUSIONS

Differential bone density must be considered when interpreting past events, such as mortuary processing or suspected acts of cannibalism. It is apparent, as exemplified by the Crow Creek massacre victims, that the taphonomic context involves a variety of forces and processes. Element and element portion survival is influenced by both extrinsic and intrinsic variables. Extrinsic forces at Crow Creek include homicide, mutilation, dismemberment, exposure, decomposition, scavenging, collection, burial, looting, excavation, transportation, cleaning, and analysis. Variables intrinsic to the bones which may affect survival include the element density, size, position (e.g. proximal-distal), and shape, and the individual's sex, age, and health. This analysis has demonstrated the association between one intrinsic variable—density—and element and element portion survival.

It is critical to consider the durability of elements and element portions when selecting elements to establish a count of the minimum number of individuals. Denser elements and denser element portions are more likely to survive and provide better estimation of the "maximum" minimum number of individuals than less dense parts. Side, sex and age differences in bone density may also alter survival of skeletal remains of some members of the burial series. Awareness of these factors allows us to better reconstruct prehistoric demography, individual burial events and diagenetic alterations for human skeletons.

In addition, this understanding will provide better predictions of which elements and portions of elements should survive, help interpret what the presence or absence of specific elements and element portions means, and reconstruct the events that tran-

spired between death and the eventual recovery and analysis of the remains.

ACKNOWLEDGMENTS

The contemporary skeletal material was collected and made available through the kindness of Dr. William M. Bass. Funds for the SPA and radioactive source were provided by the Wenner-Gren Foundation for Anthropological Research (Grant No. 5251); Ms. Pam Poe, University of Tennessee, Knoxville, oversaw the administration of the grant. Funds for the analysis of the Crow Creek specimens were provided by the U.S. Corps of Engineers, Omaha District, (Purchase Order DACW45-78-C-0018) in a contract to Dr. Larry Zimmerman, then at the University of South Dakota. Funds to aid manuscript preparation were provided to Willey through the Summer Scholars program by the CSUC University Foundation. We thank Diane Gifford-Gonzalez, Judith Habicht-Mauche, Richard L. Jantz, Charles Miksicek, Stephen P. Nawrocki, and two anonymous reviewers for editorial advice.

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